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Quick Study® ACADEMIC

WORLD'S #1 ACADEMIC OUTLINE

METEOROLOGY

The atmosphere, the Sun, radiation, cloud formations, air masses & fronts, global weather patterns & forces, severe weather, optical phenomena, and more

THE ATMOSPHERE

Gas Composition

1. The atmosphere is composed mainly of **nitrogen**, an odorless, colorless gas
2. **Oxygen** is the next most abundant element, with other gasses represented only in trace amounts
3. The atmosphere is a fluid; it has no set shape and moves easily when acted upon by external forces

Description of Composition

1. There are two ways to describe the composition of the atmosphere:
   a. By the weight of the constituents
   b. By their volume

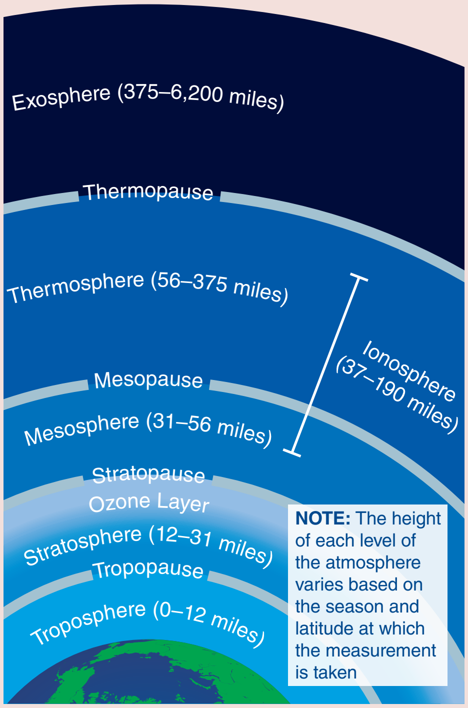
Principle Gasses in Dry Air	
Constituent	**Percent by Volume**
Nitrogen	78.084
Oxygen	20.946
Argon	.934
Carbon dioxide	.034
Ozone	.000004
Water vapor	≤4.0*

*Water vapor is a variable gas, whereas the others are more permanent

Possible Origination

1. The Earth has what is known as a **secondary atmosphere**, or an atmosphere created *after* the formation of the planet
2. The large gas planets (Jupiter, Saturn, Uranus, and Neptune) are entirely made of gas; Jupiter has a **primary atmosphere**, or an atmosphere that originated *with* the formation of the planet
3. There are two hypotheses for the formation of the Earth's atmosphere:
   a. **Outgassing:**
      i. When the Earth formed, it was a giant spinning ball of molten lava
      ii. As it cooled, gasses trapped in the lava were "belched" up by large volcanoes
      iii. The combination of these outgassed vapors and the biological transformation of the chemistry of the atmosphere by hundreds of millions of years of plant growth gave us our contemporary atmosphere
      iv. This hypothesis is more widely accepted
   b. **Comet impacts:**
      i. A comet is a giant chunk of frozen water and gasses
      ii. If many large comets struck the Earth several billion years ago, they could have left a residue of water, carbon dioxide, oxygen, and other gasses that eventually collected into the atmosphere

Levels of the Atmosphere



NOTE: The height of each level of the atmosphere varies based on the season and latitude at which the measurement is taken

1. Because the density of the atmosphere decreases exponentially with altitude, 99% of the atmosphere is within the first 20 miles of the Earth's surface

Troposphere

1. The lowest level of the atmosphere
2. Named in 1908 by Léon Teisserenc de Bort, it means "the region where air turns over"
3. The layer in which most of the clouds and weather phenomena occur
4. Has two layers:
   a. The layer that touches the Earth is called the **boundary layer** and is about 5–10 miles high at the equator
   b. The troposphere's upper limit is called the **tropopause** and varies in height with both season and location
5. In the troposphere, temperatures decrease with altitude; this is called a **lapse rate**
   a. This rate averages out to be –6.5°C for every kilometer
   b. In the tropopause, the temperature does not change with height

Stratosphere

1. The layer of the atmosphere that exists between 12–31 miles above the Earth's surface
2. The temperature in the stratosphere increases with height because the **ozone layer** is located here; when temperatures increase with height, it is called an **inversion**
   a. The ozone layer absorbs ultraviolet radiation from the Sun (*see* **Heat Transfer & the Greenhouse Effect**, p. 2, and **Ozone**, p. 6)
   b. There has been a decrease in the ozone layer due to chlorofluorocarbons (CFCs) and other man-made and natural chemical processes
   c. Scientists have found that ice crystals, due to the extremely low temperatures of this region, can also deplete ozone, but research is ongoing in this area

Mesosphere

1. The layer of the atmosphere above the stratosphere
2. The temperature in the mesosphere begins to fall, often reaching the coldest temperatures of any part of the atmosphere
   a. This cold region extends from 31–56 miles above the Earth's surface, and its temperature can reach –100°C

Thermosphere

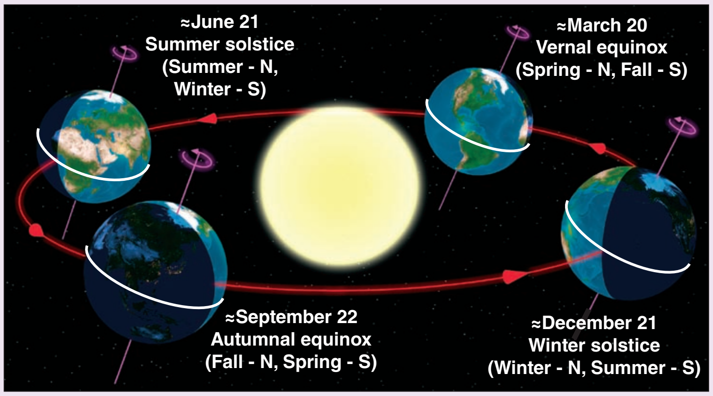
1. The layer of the atmosphere above the mesosphere
2. It starts about 56 miles above the Earth's surface
3. Here, again, the temperature begins to rise with altitude
   a. This is because the atmosphere in this region, while very thin, allows particles to move at extremely high speeds
   b. Temperature is the average kinetic energy of the particles; since the particles are moving so fast, the temperature is very high in this layer

Ionosphere

1. The layer within both the thermosphere and mesosphere in which there are enough ionized particles to affect the transmission of radio signals
   a. Radio signals bounce off the ionosphere to extend their range past the horizon
   b. This effect is stronger at night when the Sun's radiation does not affect the ionosphere
2. Ionized particles are atoms or molecules that have more electrons than protons, making them negatively charged, or more protons than electrons, making them positively charged
3. Begins about 37 miles above the Earth's surface and extends upward
4. Reflects long-wavelength, low-energy radio signals (like AM radio) back to Earth but allows short-wavelength, high-energy radio signals (like FM radio) to pass through into space

THE SUN, HEAT, TEMPERATURE & RADIATION

The Earth's Tilt & the Seasons



1. As it orbits around the Sun, the Earth spins on its axis, which is tilted with respect to the Earth-Sun **orbital plane**, not perpendicular to it
   a. The North Pole does not point directly up and down as the Earth spins but rather is inclined at 23.5° with respect to the orbital plane
2. As the Earth orbits the Sun, in a near-circular path called an **ellipse**, it remains at the same angle and pointing in the same direction; this tilt means that during a certain time of the year, the **Northern Hemisphere** is pointed toward the Sun more than the **Southern Hemisphere**
   a. During this period, the Northern Hemisphere receives more direct sunlight than the Southern Hemisphere and therefore becomes warmer; this is summer in the Northern Hemisphere and winter in the Southern Hemisphere; the first day of summer for the Northern Hemisphere is called the **summer solstice**, which has the most daylight hours of the year
      i. On or around June 21, the Sun's most direct perpendicular rays are hitting the Earth at 23.5° N latitude, the Tropic of Cancer; this is the farthest north the perpendicular rays will be

ii. On the summer solstice, there is no daylight for 24 hours from the Antarctic Circle (66.5° S) to the South Pole

b. When the Earth is on the exact opposite side of the Sun, the Southern Hemisphere gets more direct sunlight; this is summer in the Southern Hemisphere and winter in the Northern Hemisphere; the first day of winter for the Northern Hemisphere is called the **winter solstice**

i. On or around December 21, the Sun's most direct perpendicular rays are hitting the Earth at 23.5° S latitude, the Tropic of Capricorn; this is the farthest south the perpendicular rays will be

ii. On the winter solstice, there is no daylight for 24 hours from the Arctic Circle (66.5° N) to the North Pole

c. Twice a year, the Northern and Southern Hemispheres get the same amount of sunlight (12 hours of daylight and night)

i. These times are called the **autumnal and vernal equinoxes** (around September 22 and March 20, respectively)

ii. The Sun's perpendicular rays are at the equator

iii. When it is spring in the Northern Hemisphere, it is autumn in the Southern Hemisphere, and vice versa

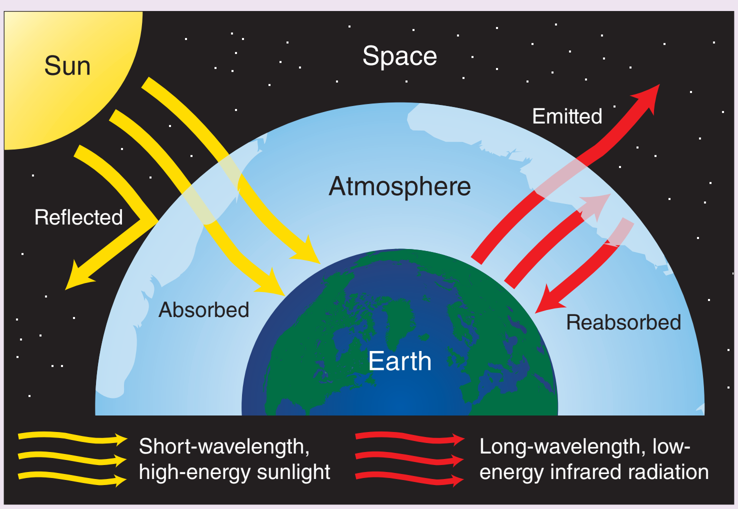
Electromagnetic Radiation

1. **Radiation** is the only mechanism of heat transfer that can transmit energy across empty space
2. The energy that powers our weather is from the Sun
   a. The colors in the visible spectrum are based on the wavelengths of the light
   b. The wavelengths within the visible spectrum are only a small fraction of the radiation from the Sun
   c. Other forms of radioactive energy are radio waves, microwaves, infrared waves, ultraviolet rays, X-rays, and gamma rays, which all differ by wavelength
3. The radiation from the Sun takes several different paths after it encounters the Earth

Possible Outcomes for Incoming Radiation	
Outcome	**% of Solar Radiation Affected**
Scattered by the atmosphere into space*	6
Reflected by clouds into space*	20
Reflected by the Earth's surface*	4
Absorbed by the atmosphere and clouds	19
Absorbed by the Earth's surface	51
*Radiation that is reflected by the Earth is called **albedo**; the albedo for the Earth is thus 30% of all solar radiation	

4. Different surfaces have different albedo
   a. Freshly fallen snow has a high albedo, whereas sand has a lower one; thus snow skiers can get sunburned just as easily as beachgoers
   b. Water, which absorbs energy, has a low albedo, so most of the energy of incoming radiation goes into heating the water and is not reflected out into space

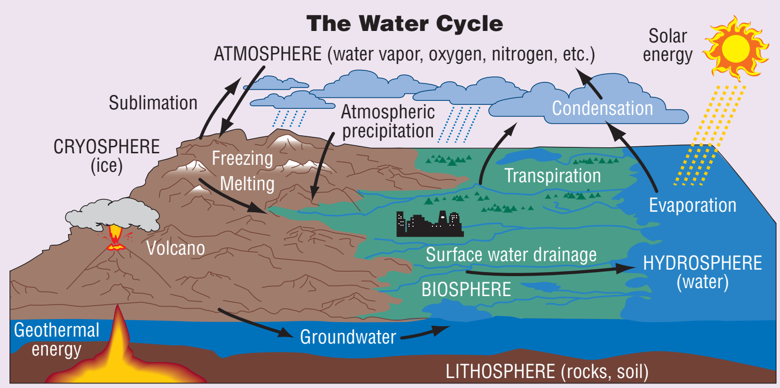
Heat Transfer & the Greenhouse Effect



1. About 51% of the solar energy that strikes the Earth is absorbed by the surface
2. The atmosphere is basically transparent to short-wavelength, high-energy light, which easily passes through the atmosphere and heats the Earth
   a. When the Earth radiates this energy away in the form of long-wavelength infrared radiation, not all of the energy escapes back into space
   b. Some of this low-energy, long-wavelength radiation is reflected back to Earth by carbon dioxide and water vapor in the atmosphere, causing the **greenhouse effect**
      i. The greenhouse effect is important for maintaining our global temperature; without any greenhouse gasses, our climate would be colder; water vapor, carbon dioxide, chlorofluorocarbons (CFCs), and methane are some greenhouse gasses
      ii. Some scientists believe that the increase in carbon dioxide, including that due to man-made processes, has affected our global climate
3. Land heats up faster and to higher temperatures than water; it also cools down quicker and to lower temperatures than water
   a. This leads to greater temperature variations for cities away from water than for those on the coast
      i. During the day, the land heats up faster and winds from the sea blow inland to replace the rising hot air, creating a **sea breeze**, or **onshore breeze**
      ii. At night, water cools down slower than the land; air from the coast blows out toward the rising air over the ocean; this is called a **land breeze**, or **off-shore breeze**
   b. A body of water acts as a stabilizer, keeping the temperature of the nearby land from getting either too hot or too cold
4. There are three ways that heat or energy is transferred:
   a. **Conduction:** Energy is transferred from molecule to molecule by direct contact; energy moves from the warmer object to the colder object
   b. **Convection:** Energy is transferred within a fluid; for example, convective thunderstorms are created when warm surface air is transferred to higher altitudes
   c. **Radiation:** Energy is transferred through the electromagnetic spectrum

Heat vs. Temperature & the Phase Change of Water

1. There are important differences between heat and temperature:
   a. **Heat** is the microscopic vibration, or energy, of the particles that constitute an object
   b. **Temperature**, however, is a way of comparing the average energy of the particles in one object to the energy in another; temperature is always relative to some specific point, such as the boiling point of water
2. The temperature where all molecular motion stops is called **absolute zero**
3. There are three main temperature scales:
   a. **Fahrenheit:** The freezing point of water is 32°F, and the boiling point is 212°F
   b. **Centigrade:** Also known as Celsius; the freezing point of water is 0°C, and the boiling point is 100°C
   c. **Kelvin:** Scientific scale where 0 K is absolute zero and has the same degree scale as centigrade; the difference between Kelvin and Centigrade is about +273°; thus the freezing temperature of water is about 273 K and the boiling point is about 373 K
4. There are three states in which water can exist in our atmosphere: solid, liquid, and gas; each phase can change into the others
   a. **Condensation:** From a vapor to a liquid; during this phase change, heat is given off in the form of **latent heat**, which is used to fuel hurricanes and thunderstorms
   b. **Evaporation:** From a liquid to a gas
   c. **Freezing:** From a liquid to a solid
   d. **Melting:** From a solid to a liquid
   e. **Sublimation:** From a solid to a vapor; dry ice transforms into a vapor without melting first via sublimation
   f. **Deposition:** From a vapor to a solid; this is how frost and snow are created



Windchill & Heat Index

1. The **windchill** and the **heat index** are *apparent temperatures*; a thermometer does not measure these temperatures; rather, they are temperatures people perceive
2. When air passes over water, it causes the water to evaporate
   a. This water may be in the ocean, a lake, or on the skin's surface
   b. When water evaporates, it absorbs energy; the more water that evaporates, the cooler the surface gets
   c. Windchill is thus created when cool air moves over a surface and carries away some heat with it, making the air feel cooler than it actually is
3. When the air is humid, evaporation cannot take place on the surface of the skin; thus perspiration does not evaporate, making it seem hotter than it really is
   a. The heat index is based on temperature and humidity, whereas windchill is based on temperature and wind speed
   b. The heat index does not always mean warmer temperatures; if the humidity is very low, evaporation takes place quickly and the person can feel cooler than the actual temperature

CLOUD FORMATIONS

High (Cirrus) Clouds

1. **Cirrus clouds** are one of the highest clouds in the atmosphere; they usually exist at altitudes between 20,000–50,000 feet above the Earth's surface
   a. Although they never actually produce rain, they often precede low-pressure systems that form rain and snow clouds
2. **Cirrostratus clouds** are the clouds that produce halos around the Sun and Moon (*see* **Halos**, p. 6)
3. **Cirrocumulus clouds** are small, white clouds that have a wavelike pattern to them
4. Clouds produced from a fast-moving airplane are called **contrails**

Middle (Alto) Clouds

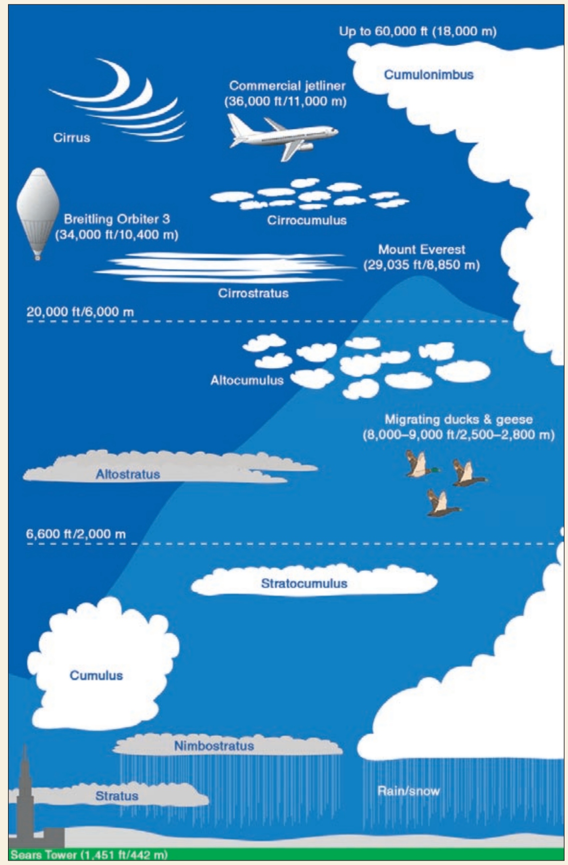
1. Mid-level clouds exist at altitudes between about 6,600–20,000 feet above the Earth's surface
2. **Altocumulus clouds** are generally fluffy and white; they are very common on partly sunny days
3. **Altostratus clouds** are grayish, uniformly textured clouds; they are never white; they are characterized by the Sun being visible through them without a halo

Low Clouds

1. Low clouds are the stratus, nimbostratus, and stratocumulus, as well as the vertical cumulus and cumulonimbus
2. **Stratus clouds** are low, gray clouds that cover the sky uniformly
3. **Nimbostratus clouds** are stratus clouds that produce rain
4. **Stratocumulus clouds** are stratus clouds that cover the sky uniformly but do not produce rain
5. **Cumulus clouds** are low, cotton ball–like, fluffy clouds that do not produce rain
6. **Cumulonimbus clouds** produce lightning storms, hail, and tornadoes; the top of the cloud may be high enough to penetrate into the jet stream, causing the characteristic anvil-shaped top
   a. These clouds are produced when unstable air (which is hotter than its surroundings) is lifted into the upper atmosphere; as the warm air rises, it expands
   b. This expansion increases the volume of the air and decreases the temperature
   c. If the temperature reaches the **dew point**, condensation occurs and a cloud is created
      i. The dew point is the temperature at which the water vapor in the air condenses
      ii. If the dew point is within 3°F of the air temperature, clouds and fog can form

Other Clouds

1. **Mammatus clouds**
   a. These are bulging, lumpy clouds sometimes seen on the underbelly of a cumulonimbus cloud
   b. They are often associated with severe weather
2. **Orographic clouds**
   a. These types of clouds are produced when warm air is lifted up by mountains into the upper, cooler atmosphere
   b. The warm air is cooled and therefore produces clouds and rain on the **windward** side of the mountain
   c. As the air flows down the other side (the **leeward** side) of the mountain, it becomes dryer and warmer than when it first went up the mountain
   d. One type of cloud that is created in this process is called a **lenticular cloud**, which has a UFO-shaped appearance



AIR MASSES & FRONTS

Air Masses

1. The air masses that influence U.S. weather fall into roughly seven different categories (see table)
2. They are classified according to their source region and the nature of their source location (land or ocean)

U.S. Air Masses & Their Functions

Name	Function
Continental Polar	Cold, dry air from the interior of Canada and Alaska that produces cold waves in the winter and heavy snows in the Great Lakes region
Continental Arctic	Very cold, dry air from the Arctic basin and Greenland ice cap that produces cold waves in the winter
Maritime Polar (Pacific)	Mild, cool air from the northern Pacific Ocean that produces heavy orographic precipitation in the Washington State area, low clouds in the summer, and low stratus clouds and fog in the winter
Maritime Tropic	Warm, humid air from the Gulf of Mexico that brings hot, humid conditions and frequent thunderstorms
Maritime Polar (Atlantic)	Cold, humid air from the northwestern Atlantic that brings periods of cool, clear weather in the summer and an occasional severe storm in the winter
Maritime Equatorial	Warm, humid air from the subtropical Pacific Ocean that brings fog and drizzling rains to the southwestern United States in the winter
Continental Tropical	Hot, dry air from the southwestern United States and northern Mexico that brings very desiccated conditions, as well as occasional droughts, to the Great Plains

3. **Cyclones and anticyclones**
   a. Temperature variations cause pressure differences in the air, which cause high winds
   b. Around an area of low pressure, the wind tends to move in a characteristic counterclockwise motion (clockwise in the Southern Hemisphere) called **cyclonic flow**; the low-pressure area is called a **cyclone**
   c. Around an area of high pressure, the wind has a characteristic clockwise motion (counterclockwise in the Southern Hemisphere) called **anticyclonic flow**; the high-pressure area is called an **anticyclone**

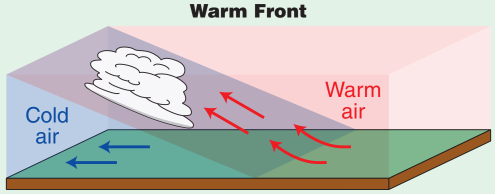
Fronts

1. A **front** is the boundary between two different air masses when the air masses collide
   a. The term *front* comes from "the front lines" during war; this is where the action of weather occurs
   b. Changes that occur during the passage of a front include changes in temperature, pressure, wind speed and direction, humidity, and sky conditions

Warm Fronts

1. Since warm air is lighter than cool air, when a **warm front** is moving through an area, the warm air is forced up and over the cooler air ahead of it (called **overrunning**), thereby condensing it and producing rain
2. A warm front tends to produce light to moderate precipitation over an extended period for a large area due to this front's gentle sloping shape
3. The clouds often associated with these types of fronts are cirrus, altostratus, and nimbostratus

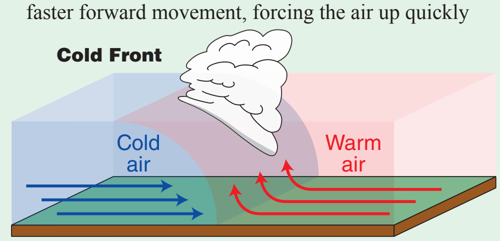
Warm Front



Cold Fronts

1. Since cold air is heavier than warm air, when a **cold front** is passing through an area, the cold air is denser and forces the warmer, humid air up
   a. Cold fronts move faster than warm fronts
   b. The cold air mass lifts the warm air that it is moving toward, thereby cooling the warm air mass and causing clouds and rain
2. The rain caused by cold fronts tends to be more localized and more intense, as a cold front has a steeper slope and faster forward movement, forcing the air up quickly

Cold Front



Stationary Fronts

1. A **stationary front** is the boundary line between two different air masses that are not moving in any direction
2. The stationary front produces long periods of rain and can cause localized flooding

Occluded Fronts

1. An **occluded front** is a situation in which a cold front overtakes a warm front from behind
2. In this case, the cooler air of the cold front, which moves faster than the warm front, lifts the warm front when it overtakes it, often forming complex weather patterns that last until the warm front is completely overtaken

Dry Lines

1. A **dry line** does not usually have all the same characteristics of a front, such as the characteristic temperature changes and wind shifts; rather, it is a front-like boundary between very humid air and very dry air
2. The biggest change with a passage of a dry line is the large drop in humidity when the dry line passes
3. Dry lines usually occur in Texas and can produce severe thunderstorms due to the interaction between dry air coming off the Rocky Mountains and humid air coming off the Gulf of Mexico

WEATHER INSTRUMENTS

Weather Balloons

1. Weather balloons often carry aloft lightweight scientific packages that measure such things as temperature, pressure, relative humidity, and altitude
2. Balloons that transmit this information via radio signals are called **radiosondes**
3. Weather balloons are released twice a day at the same time (noon and midnight GMT) around the Earth, and release sites vary from airports to weather stations; this allows scientists to collect data from around the world for the exact same moment in time

Satellites

1. There are two main types of satellites:
   a. **Geostationary satellites** are about 23,000 miles above the equator and have an orbital speed the same as the Earth; thus they are over the same location at all times
   b. **Polar-orbiting satellites** are hundreds of miles above the Earth's surface and orbit around the Earth from pole to pole
2. There are two main images that satellites send:
   a. **Visible images** are highly detailed photos; they can only be taken during the daylight when the Sun is shining on the Earth's surface
   b. **Infrared images** measure the amount of infrared radiation emitted at night, thus they can be used when taking visible images is not possible

Radars

1. A radar sends out a microwave signal; when the signal reaches a storm, a part of the energy is bounced back to the radar site; the time of the delay and the strength of the returning signal determine the strength and location of the storm
2. **Doppler radar** measures precipitation and wind speeds to and from the station

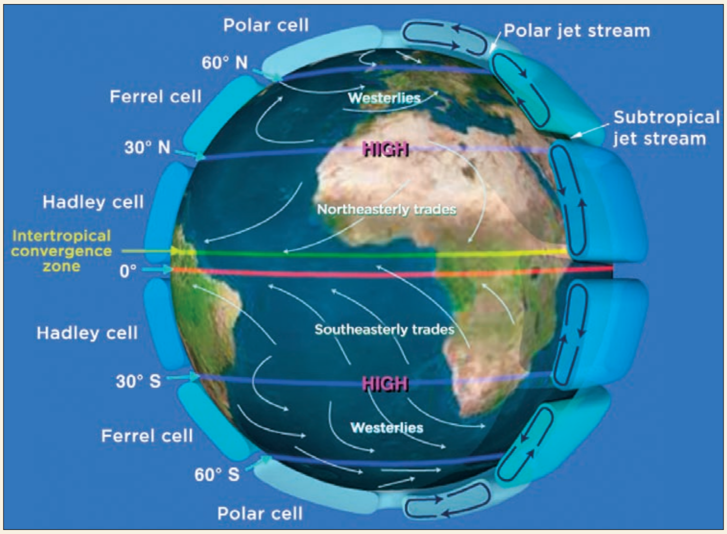
Other Weather Instruments

1. **Thermometer:** Measures temperature
2. **Hygrometer:** Measures humidity
3. **Anemometer:** Measures wind speed; the most common have three cups that spin around a central axis
4. **Wind vane:** Measures wind direction; wind is always stated in the direction that the wind is coming *from* (e.g., a north wind is coming from the north)
5. **Barometer:** Measures air pressure
   a. **Mercury barometers** measure inches of mercury that are being held up by the atmosphere; the standard sea-level air pressure is 29.92 inches of mercury
   b. **Aneroid (without liquid) barometers** measure air pressure; these are the typical barometers seen in homes
6. **Rain gauge:** Measures precipitation

GLOBAL WEATHER PATTERNS & FORCES

Global Air Circulation

1. Hot air at the equator rises and travels north and south, precipitating rain as it ascends
2. The dry air comes down at about 30° N and S latitude (called the **horse latitudes**), where most of the world's deserts tend to be
   a. This cycle is known as the **Hadley cell**, which lies in the equatorial region
   b. The winds in Hadley cells, both north and south of the equator, tend to blow toward the west
   c. These winds, named the **trade winds**, facilitated much of the New World exploration by European explorers
3. The region around the equator where the hot air rises is known as the **doldrums**
   a. Because there is so little air movement in this region, sailboats have difficulty moving anywhere, hence the phrase "in the doldrums"
4. The region north of the Hadley cell, 30° N to about 60° N, is a circulation called the **Ferrel cell**
   a. Since the Ferrel cell has a reverse rotation, the surface winds blow toward the east, creating the prevailing **westerlies**
   b. The Ferrel cell is partially the reason why most of the weather in the United States moves west to east
   c. The westerlies often give airplanes traveling from the United States to Europe very strong tailwinds
5. Cold air at the poles descends, travels toward the equator, and heats up where it rises near the Arctic and Antarctic Circles, which are located at 66.5° N and S, respectively
   a. As the air rises, it releases rain; this circulation is called a **polar cell**
   b. Like the Hadley cell's circulation, the polar cell moves winds, called the **polar easterlies**, toward the west



6. **Jets streams** are "rivers" of fast-moving air that occur between the global cells and circulate around the planet; these winds can reach very high speeds
   a. The **subtropical jet stream** occurs between the Hadley cell and the Ferrel cell
   b. The **polar jet stream** occurs between the Ferrel cell and the polar cell
   c. These main jet streams move the air west to east around the Earth and can direct storms across the globe
   d. They are located near the top of the troposphere

El Niño

1. **El Niño**, "the boy," was named by the Peruvians because the patterns reflected that "he" would usually come around Christmastime
2. El Niño is a major change in the surface temperature of part of the Pacific Ocean, where a large region of warm surface water forms off the coast of Peru
   a. First, cold air from the Arctic and Antarctic converges at the equator off the coast of Peru
   b. The air mass then heads westward, toward Indonesia, where a semipermanent, low-pressure system exists
   c. When a high-pressure system develops over Indonesia, the trade winds stop blowing from the east to the west, and warm water begins to accumulate off the coast of Peru (as it is no longer being cooled by the steady flow of cold air)
3. A change in the temperature of the water beneath a body of air will change the way the body of air behaves
   a. A major change in the surface temperature of a large part of the ocean will have a major effect on global weather patterns
4. The meteorological effects of El Niño are very complex, but they all begin with this region of warm water off the coast of Peru
   a. El Niño can bring a lot of rainfall to southern California
   b. An El Niño during the summer can suppress hurricane formation and reduce the number of tropical systems in the Atlantic Ocean

La Niña

1. A large region of cold surface water off the coast of Peru is referred to as **La Niña**
   a. This occurs when the trade winds are stronger than normal and push the warmer water of the Pacific Ocean toward the west
   b. Moving the waters westward creates an upwelling of the cooler waters from the ocean floor to the surface
2. La Niña, "the girl," is so named for the opposite effects in comparison to El Niño's
   a. A greater amount of hurricanes are usually expected with a La Niña event

Forces That Act on Wind & Air

1. There are three main forces that act on wind and air: the pressure gradient force, the Coriolis force, and geostrophic wind
2. The **pressure gradient force** is the change of pressure over distance; the greater the pressure difference between two locations, the stronger the wind or force will be
   a. The pressure gradient force is what causes the winds to move so fast in a hurricane and tornado; the pressure differences between the center of circulation and the outside surrounding area are so great that the wind will move rapidly from the higher pressure to the lower pressure
   b. This can be seen on a weather map; **isobars** (lines of equal pressure) that are packed together indicate a rapid change in pressure over a relatively short distance
3. The **Coriolis force** is named after the 19th-century French scientist Gaspard-Gustave Coriolis; this force moves objects off a straight-line path due to the rotation of the Earth
   a. If the Earth did not rotate, the wind and air would move in a straight line from high to low pressure; since the Earth does rotate, it will "bend" the path of the object or air to the right of the straight-line path in the Northern Hemisphere and to the left in the Southern Hemisphere
   b. The magnitude of this effect is based on the speed, mass, and latitude of the object
      i. The faster and heavier the object, the more to the right or left it will be bent off of the straight path

ii. Latitude also plays an important role; the closer the object is to the equator, the less of a Coriolis force there is; this is why hurricanes cannot form along the equator; however, the Coriolis effect is strongest at the poles

4. **Geostrophic wind** is the result of the pressure gradient force and Coriolis force working in opposition to each other; this resulting force moves the air around a high- or low-pressure area
   a. Geostrophic wind moves the air clockwise around a high-pressure center and counterclockwise around a low-pressure center in the Northern Hemisphere
   b. The rotations are opposite in the Southern Hemisphere

SEVERE WEATHER: FORMATIONS, DAMAGE & DETECTION

Winter Storms

1. Winter storms are often named after their starting location or the path they will take; the strength of a winter storm depends on many factors, including how much water vapor is available to create snowfall
2. An **Alberta clipper** is a fast-moving snowstorm that originates in Alberta, Canada
   a. These storms produce a dusting of up to an inch of snow along the U.S.-Canadian border
3. A **nor'easter** is a storm that starts in the Gulf of Mexico and rides up the East Coast of the United States
   a. A nor'easter can bring heavy snows and blizzard conditions to New England and other areas along the East Coast
   b. Some of these storms have been as strong as hurricanes and have set many snowfall records for cities along the eastern seacoast
4. **Lake-effect snow** affects the leeward, or downwind, side of the Great Lakes in the United States; it can bring heavy snows for long periods of time
   a. When cold, dry air over Canada flows over the open waters of the Great Lakes, it can take the water vapor and turn it into snow as it travels onshore
   b. Lake-effect storms occur during the early winter season when the lakes have not yet frozen over

Thunderstorms

1. **Thunderstorms** are caused by warm, moist air rising through the atmosphere
   a. As the air rises, it undergoes adiabatic cooling (i.e., cooling that results from gas expanding)
   b. If the rising air remains warmer than the surrounding air, it will continue to rise
   c. When it reaches sufficient altitude, it cools to the dew point and rain results
2. The top of a thundercloud can reach over 50,000 feet above the ground

Types of Winds & Their Forces		
Beaufort Force	**Name**	**Winds (mph)**
0	Calm	<1
1	Light air	1–3
2	Light breeze	4–7
3	Gentle breeze	8–12
4	Moderate breeze	13–18
5	Fresh breeze	19–24
6	Strong breeze	25–31
7	Moderate gale	32–38
8	Fresh gale	39–46
9	Strong gale	47–54
10	Whole gale	55–63
11	Violent storm	64–73
12	Hurricane	≥74

Updrafts & Downdrafts

1. Inside a thunderstorm, there are very strong winds, which result from temperature and pressure differences within the cloud
   a. Winds going up are called **updrafts** and are caused by hot air being lifted
   b. Downward winds are called **downdrafts**
      i. The rain (which causes downdrafts) falls, cooling the air and therefore making it heavier
      ii. A very intense downdraft is called a **downburst** and can generate winds of over 70 mph
      iii. Very small downbursts are called **microbursts**
2. Downbursts and microbursts, which form underneath thunderstorms, can interact with aircraft as they take off and land, causing accidents

Tornadoes

1. A **tornado** is a whirling vortex of wind; the tornado season runs from March through June, but tornadoes can occur in any month
2. Strictly defined, a **funnel** is the column of wind that descends from the cloud but does not yet touch the Earth
3. The tornado begins when the funnel cloud makes contact with something on the ground or the ground itself
4. While the specific causes of tornadoes are currently unknown, the overall steps to create these storms are known:
   a. Jet streams in two different levels move in different directions, causing the air to roll like a pencil on a table
   b. The difference in temperature between the two streams creates an unstable atmosphere where warm, humid air is at the surface and cold, dry air is above it
   c. A thunderstorm thus grows, and the rising air lifts this rolling air vertically
   d. A lowered section of the southwest part of a cloud forms; this is called a **wall cloud**, and a funnel cloud descends from it

Tornado Facts

1. More tornadoes occur in **Tornado Alley** (encompassing Texas, Missouri, Kansas, and Oklahoma, among other states) than in any other place on Earth
2. Tornadoes occur most frequently in May but have occurred in every month throughout the year
3. The strongest wind in a tornado can be as fast as 300 mph
4. The average length of a tornado's path is about 1–2 miles long and 50 yards wide; tornadoes vary in size and are usually on the ground for about 10 minutes; larger storms can be on the ground for a much longer time; the record for this is the Tri-State Tornado, which, on March 18, 1925, was on the ground for 35 hours and traveled 219 miles through Missouri, Illinois, and Indiana
5. The deadliest tornado outbreak on record occurred on April 3–4, 1974, when 148 tornadoes struck 13 states and killed 330 people; however, the largest tornado outbreak occurred during April 26–28, 2011, in which over 300 tornadoes were reported across 15 states
6. **Waterspouts** are essentially tornadoes over water, but they tend to be much weaker than tornadoes over land and usually dissipate before they reach the shore
7. Most tornadoes spin counterclockwise, but 1 in 100 spin clockwise—for reasons scientists have yet to determine

Enhanced Fujita Scale		
Scale Number	**Winds (mph)***	**Damage**
0	65–85	Gale
1	86–110	Weak
2	111–135	Strong
3	136–165	Severe
4	166–200	Devastating
5	>200	Incredible

*The Enhanced Fujita Scale is based on a three-second gust

Hurricanes

1. The initial step toward the formation of a hurricane begins with a cluster of thunderstorms called a **tropical wave**
   a. The tropical wave becomes a **tropical depression** when the thunderstorms organize themselves into a single system
2. The next stage is the more organized **tropical storm**, which has sustained winds of 39–73 mph; it is at this point that the system gets a name
3. When the sustained winds reach the 74 mph mark, the storm becomes a **hurricane**
   a. Hurricanes have a characteristic spiral shape
   b. The heaviest squalls are found in the **eye wall**; the eye at the center has relatively calm winds
   c. The entire storm may be several hundred miles across
4. Often, the most damaging part of a hurricane is the **storm surge**
   a. The storm surge is an upswelling of water that accompanies the hurricane; this upswelling brings cooler waters to the ocean's surface
   b. The hurricane has a very low barometric pressure, and it literally sucks the water up into a bulge
      i. The strong winds also whip the waves on top of the tidal bulge up to heights of 25 feet above normal sea level
      ii. These tidal surges cause a great deal of damage and loss of life, especially on the right side of the forward motion of the hurricane (in the Northern Hemisphere)
      iii. The right side is especially dangerous because the speed of the storm and the speed of the wind within the storm are going in the same direction, increasing the wind speed relative to the ground
      iv. On the left side of the storm, the wind speed and the speed of the storm act in opposition to each other, which slows the wind relative to the ground

Hurricane Facts

1. The year 2005 was a landmark year for hurricanes: it had the most named storms (28), the most hurricanes (15), and the most major hurricanes making landfall in the United States (4); in addition, the allotment of names was used up for the first time in 2005; Greek letters were used after the final name on the list
2. Hurricanes started to get their names in 1953; in 1979, male names were added to the list; names, based on names familiar to people living in hurricane-prevalent areas, are recycled every six years
3. A hurricane's name is retired if the storm caused significant damage (e.g., Andrew, Katrina, and Wilma)
4. There have been three category 5 hurricanes to strike the United States: an unnamed storm in 1935 that hit the Florida Keys; Hurricane Camille in 1969, which hit Mississippi; and 1992's Hurricane Andrew, which struck Miami-Dade County, Florida
5. In the Northern Hemisphere, a hurricane spins counter-clockwise; in the Southern Hemisphere, a hurricane spins clockwise
6. In the northwest Pacific, hurricanes are known as **typhoons**; they are known as **cyclones** around the Indian Ocean
7. On average, there are about six hurricanes every year in the Atlantic; the hurricane season runs from June through November
8. The peak of hurricane season occurs around September 10

Saffir-Simpson Hurricane Scale		
Category	**Winds (mph)**	**Damage**
1	74–95	Minimal
2	96–110	Moderate
3	111–129	Extensive
4	130–156	Extreme
5	≥157	Catastrophic

Lightning

1. Excess **electrons** in certain parts of cumulonimbus clouds cause **lightning**
   a. Within the cloud, air is swirling very fast
   b. Ice crystals collide with other ice crystals, which is believed to cause a separation of charge that occurs within the thunderstorm
   c. The electrons congregate at the bottom of the cloud, giving it a negative electric charge; when the charge has become too strong for the atmosphere to insulate, a streamer of negative charges races out of the cloud in a stepped fashion; these are called **stepped leaders**
   d. When the stepped leaders approach the Earth's surface, the Earth sends **positive streamers** up toward the approaching stepped leaders
   e. When the stepped leaders touch a positive streamer from the ground, a **return stroke**, or **lightning bolt**, is produced
      i. The flash heats the air in the immediate vicinity of the lightning bolt, which causes the air to expand explosively
      ii. **Thunder** is caused by the pressure wave of this expanding, superheated air

Lightning Facts

1. The temperature of a lightning bolt can be as high as 55,000°F, which is almost six times hotter than the surface of the Sun
2. When you see a lightning flash, count the seconds until you hear the resulting thunder; for every 5 seconds that elapse, the bolt is 1 mile away from your location
3. Lightning's electrical potential energy can be as high as 100 million volts
4. **Heat lightning** is when a lightning flash can be seen but is too far away to be heard; all lightning produces thunder—the environment's "heat" does not generate lightning, as the name implies
5. **Sheet lightning** is when the thunderstorm cloud lights up from the inside
6. **Cloud-to-cloud lightning** is the most common
7. Florida gets more lightning strikes than anywhere else in the United States; there is a "lightning alley" running through the state

Air Pollution

Sources

1. The major sources of **air pollution** are coal combustion, agricultural by-products, manufacturing waste, and the combustion of oil from cars, trucks, and factories
2. The direct introduction of pollutants into the atmosphere is called **primary pollution**
3. Substances that react chemically with other constituents of the atmosphere to form harmful compounds are called **secondary pollutants**

Impact on Nature

1. Massive quantities of sulfur dioxide and nitrogen oxides are emitted into the atmosphere every year by industrial processes and automobiles; once there, they are transformed into weak nitric and sulfuric acids by very complex processes, leading to **acid rain**
   a. The pH of acid rain is about 4.2–4.4, midway between concentrated sulfuric acid and distilled water (i.e., neutral pH)
   b. Acid rain has killed trees and led to the death of large quantities of fish in lakes
   c. Due to better air pollution controls in the West, acid rain is less common there; however, it still remains an issue for areas with large developing industries and fewer rules to combat pollution, such as Asia
2. It is unequivocal that the Earth's temperatures are rising; the general consensus in the scientific community, as well as among national governments, is that this warming is due to anthropogenic causes (human processes); however, this issue remains controversial
   a. Warming of the Earth can change global sea levels and cause desertification of forests, as well as other changes within ecosystems

Impact on Humans

1. One type of air pollution is **particulate matter**, or tiny particles suspended in the air
2. They contribute greatly to smog and other air pollution problems in major cities and industrial centers
3. Asthma and other lung diseases are exacerbated by the quantity of particulate matter in the atmosphere

Ozone

1. The ozone layer, located in the stratosphere, screens out harmful ultraviolet rays from the Sun
2. Man-made chemicals called **chlorofluoro-carbons (CFCs)**, used in refrigeration, aerosols, and insulation, tend to destroy the ozone layer
   a. CFCs are made of chlorine atoms, which are able to break the bonds within the ozone molecule (O_3), creating a free oxygen atom and the molecule we breathe (O_2); the CFC molecule is then able to move on to the next ozone molecule
   b. How long this process can continue is still unclear to scientists
3. The large quantities of man-made chemicals in the upper atmosphere have altered the chemistry of the ozone formation process and created holes in the ozone layer over the polar regions
4. While exposure to **ultraviolet radiation type B (UVB)** causes a reaction that produces vitamin D in our bodies, giving us our daily requirement of vitamin D, overexposure causes most skin damage, leading to skin cancer; UVA exacerbates UVB damage to the skin even further

OPTICAL PHENOMENA

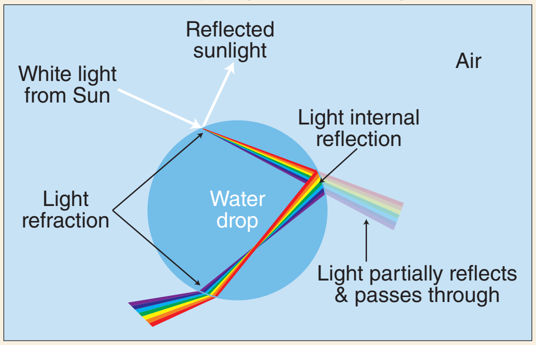
Auroras

1. **Auroras** are glowing regions of the atmosphere caused by energetic particles traveling along the Earth's magnetic field lines like beads on a wire via solar wind; these particles are blasted toward the Earth by eruptions on the Sun's surface
2. When large quantities of these particles pass through the atmosphere at the same time, they cause a glow centered near the magnetic poles of the planet, by the Earth's magnetic field

Mirages

1. When air is very hot, like it is just above a roadway on a summer day, it can reflect light just like a mirror
2. Often, the air reflects the sky, making it appear as if water is on the ground
   a. To see a mirage, a low-level viewing angle is required
   b. As you get closer to a mirage, your viewing angle changes and thus the mirage disappears

Rainbows & Rayleigh Scattering



1. **Rainbows** occur when you are looking into a rain or storm cloud and the Sun is behind you; like the common myth, this is why you will never get the pot of gold at the end of the rainbow, as once you were to reach the rainbow, you would be in the rain itself and not between the rain and the Sun
2. The Sun's light gets refracted and reflected within each raindrop; this causes the Sun's light to break apart into the different colors of the spectrum
3. Sometimes there is a double reflection within the raindrop and a **secondary rainbow** is formed
   a. The secondary rainbow is always higher in the sky than the primary rainbow, and the colors are reversed
4. Rainbows only occur during the mornings and late afternoons when the Sun is lower in the sky
5. **Moonbows** and **fogbows** can also occur, but their colors are often muted and they are not as common as rainbows
6. **Rayleigh scattering** is the scattering of blue light by atoms in the atmosphere; due to the density of Earth's atmosphere, the other colors are not affected, so when we look at the sky, we see only blue light being scattered toward us; **NOTE:** Because other planets' atmospheres have different compositions and thus different densities, it is thought that their skies may be different colors

Halos

1. Sometimes there is a **halo**, or ring, around the Sun or Moon; ice crystals high in the atmosphere cause halos
2. Cirrostratus clouds, which are made up of ice crystals from nearby thunderstorms, bend and refract the light so it appears that a halo is encircling the Moon or Sun
3. Halos often mean that a thunderstorm is nearby and thus predict rainfall in the area soon

Twinkling Stars

1. Stars twinkle as their light passes through the many layers of the atmosphere; faraway stars appear very dim when their light reaches Earth; this light has a hard time passing through the different densities of the atmosphere and thus we perceive the star as a flicker of light
2. The Moon and planets are much brighter, so their light does not flicker; if you see a "star" in the night sky that does not flicker, you are looking at a planet in our solar system

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